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ORIGINAL PAPER

Effect of microenvironmental quantitative regulation on growth of Korean pine trees planted under secondary forest

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Abstract: Korean pine (*Pinus koraiensis*) and broadleaved mixed forest in Northeast China has been changed regressively into secondary forest with almost no conifers. Planting Korean pine trees under the canopy of secondary forest is a feasible approach for recovering Korean pine and broadleaved mixed forest. For establishing an effective growth promotion method for under-canopy planted young Korean pine trees, two stands were selected as the experiment plots, Stand A (planted in 1989) and Stand B (planted in 1982), and an experiment of microenvironment regulation was conducted relying mainly on Opening degree (K=1, K=1.5, K=2, CK) in 2004. The results were shown that the adjustment had promoted growth of diameter and height of Korean pine planted in Stand A and Stand B, and had a significant influence on the growth rate of basal diameter, diameter at breast height and height in the two growth stands. The four years periodic increment of mean diameter and height of Korean pine planted in 1989 and in 1982 after regulation in K=1 level were 63.4% (D_0) and 82.7% (H), 64.8% ($D_{1.3}$) and 69.7% (H) higher than that of control respectively. Quantitative regulation had significant influence on specific leaf area of Korean pine planted in 1989, and the current year specific leaf area (SLA) was lager than perennial year SLA. Quality indexes of natural pruning capacity, normal form quotient and crown size was not significantly changed but shown a positive tendency. The regulation scheme of Opening degree K=1 might be proper for adjusting the microenvironment of Korean pine trees planted under the canopy of secondary forest when the Korean pine trees were in the growth period of 15 to 26 years old in the experiment region.

Keywords: *Pinus koraiensis*; under canopy planting; microenvironment; quantitative regulation; opening degree

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Introduction

Korean pine (*Pinus koraiensis* Sieb. et Zucc.) is the ecologically key species in temperate zonal climax forest in Northeast China. The zonal climax forest dominated by Korean pine and formed by the pine mixed with some other coniferous species like *Picea koraiensis, Abies nephrolepis,* and many broadleaved species like *Fraxinus mandshurica, Juglans mandshurica, Phellodendron amrense, Tilia amurensis, Betula costata, Acer mono* and *Quercus mongolica* in different composition proportions associating with different site conditions. Because all of these species are high-quality timber production species, the virgin mixed forest was destroyed seriously by excessive timber harvest since the beginning of the 20th century (Zhou 1982; Hu 1983; Chen et al. 1984) and has been developed to various types of secondary forests with almost no conifers and even no seed source of conifers (Hu 1983; Chen et al. 1984; Wang 1998). For recovering the Korean pine dominated climax-like mixed forest, a dynamic management strategy of "planting conifers and reserving natural broadleaved" was gradually developed (Chen and Zhou 1961; Zhou et al. 1965; Zhou 1982; Hu 1983; Chen et al. 1984, 1985; Wang 1998). The basic meaning of the terminology is artificially planting conifer species (mainly Korean pine) at the cutting land or into the stand of secondary forests derived from the zonal climax forest, growing them together with the existing or naturally regenerated broadleaved tree species, and form climax-like mixed forest. Planting Korean pine under the canopy of the secondary forest is one of the feasible approaches developed following the idea of the strategy (Zhang et al. 2003) and large-area mixed forest are established by this approach in eastern forest region of Northeast China. Since this approach was put into practice, many researches were conducted on how to regulate the

structure and species relationship in such mixed forest, but most of the researches were in stand level and just a few referred to regulate the pine individual microenvironment (Li and Wang 1991; Li et al. 1992; Li et al. 1993; Zhang et al. 2003). Thinning and tending of such mixed forests was mainly qualitatively and experimentally (Li and Wang 1991; Zhang et al. 2003).

In describing and regulating the relationship among species and neighboring trees in mixed forest, some quantitative indexes such as Opening degree, Size differentiation, Species mingling and Contagion were developed. Opening degree was developed by Luo et al (1984) for describing relative light intensity of certain spot within forest; it was significantly correlated with practice light intensity and could reflect well the relationship between under-canopy plants and upper trees. Size differentiation, Species mingling, and Contagion was established by Hui and Gadow (Hui et al. 1999a, 1999b; Hui and Gadow 2001; Aguirre et al. 2003; Hui and Hu 2006) for describing the relationship among neighboring trees, space segregation degree of different species in mixed forest and distribution pattern of neighboring trees respectively. In order to establish a scientifically quantitative regulation method for growth space of the under-canopy planted pine trees in secondary forest that can effectively promote the growth of the pine as well as the broadleaved trees, a series of investigation were conducted. Firstly, we investigated the growth status of Korean pine trees planted under canopy of secondary forest in two typical stands, secondly we evaluated the status based on Opening degree, Size differentiation, Species mingling and Contagion, then we set 24 experimental plots based on the evaluation result (Zhang et al. 2004; Shen et al. 2004; Fan et al. 2004, 2005). Here we report the regulation effects on growth and morphological characteristics obtained after four years experiment.

Materials and methods

Experiment sites

Experiment area is located in Maoershan Experiment Forest Farm of Northeast Forestry University in Shangzhi City, Heilongjiang Province, China. The forest farm was in west extension of Zhangguangcailing Range of Changbai Mountains (45°21′–45°25′N, 127°30′–127°34′ E) with mean altitude of 300 m. The mean annual temperature and rainfall is 2.8℃ and 723.8 mm. The two stands were selected in compartment Taiping (Korean pine was planted in 1989 and 15 years old in 2003, marked as Stand A) and Zhonglin (Korean pine was planted in 1982 and 21 years old in 2003, marked as Stand B) respectively, and they are natural secondary forest being composed mainly of *F. mandshurica*, *J. mandshurica*, *Q. mongolica*, *B. platyphylla*, *Populus davidiana*, *T. mandshurica, A. mono, A. tegmentosum, A. ginnala, A. mandshuricum, Ulmus davidiana, U. laciniata, Syringa reticulata* var. *mandshurica* and *Padus maachii*. Two-year-old seedlings of Korean pine was planted with density 2 000 trees·ha^{-1} under canopy in the two stands after tending thinning of the broadleaved trees. Till the year 2003, the stand planted in 1982 was lightly thinned with the intensity of 30% in 1992, while the stand planted in 1989 was not thinned.

Primary investigation results

In 2003, nine sample plots in 400 m^2 represented 3 kinds of slope locations in each experiment site were investigated. Besides tally and vegetation composition and abundance investigation, microenvironment factors around each Korean pine trees were also investigated. The factors included soil depth and humus layer thickness, height and species and the distance to neighboring upper broadleaved trees, direct light. The position of each pine trees and broadleaved trees that the diameter exceeded 1.9 cm were located on coordinate paper. The results were shown that if U=0 or U=0.25, M=0.5 and W=0.5, the pine trees will be in dominant or sub-dominant position, two of the four neighboring trees around pine trees will be broadleaved trees, and the neighboring trees around pine trees were in random distribution patterns (Zhang et al. 2004; Fan et al. 2004, 2005). This status was favorable to the growth of Korean pine trees. However, the results showed no ideal/relational K value for pine trees in the two stands, for in Stand A the K value was changed between 2 to 6 and in Stand B all of the K value was almost 1.5 (Zhang et al. 2004; Fan et al. 2004).

Quantitative regulation indexes

Open degree **(K)** is defined as the sum of the ratio of the distance from the reference tree to the nearest upper neighbor trees in each quadrat to their height of the upper trees (Luo et al. 1984; Li et al. 1992; Zhang et al. 2004) (see Appendix 1). The longer the distance to the neighbor trees and the lower the upper tree height, the larger is the K value; consequently, the more favorable to the growth of the reference tree.

Size differentiation (U) is defined as the proportion of the number of nearest neighbors bigger than the given reference tree to all number of the nearest neighbors of the reference tree (Hui et al. 1999a; Aguirre et al. 2003; Zhang et al. 2004)

Species mingling (M) was defined as the proportion of the number of the nearest neighbors that do not belong to the same species as the reference tree (Hui and Hu 2001; Aguirre et al. 2003; Zhang et al. 2004).

The contagion (W) was defined as the proportion of angles between the four neighboring trees which are smaller than the standard angle (Hui et al. 1999b; Aguirre et al. 2003; Zhang et al., 2004).

Experiment design

According to the primary results, we set size differentiation, species mingling and contagion in a fixed value of U=0 or U=0.25, M=0.5 and W=0.5 for each plot, but three levels of K=1, K=1.5 and K=2 for Opening degree and each K level were repeated 3 times. Including controls without thinning and tending, totally 24 experiment plots were set in March 2004 in the two stands (12 plots in each stand). The size of each plot was 400 m^2 (20 m × 20 m). The sample plots set in stands with Korean pine

trees planted in 1989 and 1982 were marked as stand A and stand B respectively. The design was shown in Table 1 and the mean tree number, basal diameter, diameter at breast height, and tree height for Korean pine and broadleaved trees were shown in Table 2.

Table 1. Experiment design of quantitative regulation of the micro-environment for Korean pine trees planted in 1989 (Stand A) and 1982 (Stand B) under secondary forest according to opening degree in 2004

Opening degree classes	Levels (repeats) in Stand A	Levels (repeats) in Stand B
K_1=1	A1 (A1-1, A1-2, A1-3)	B1 (B1-1, B1-2, B1-3)
K_2=1.5	A2 (A2-1, A2-2, A2-3)	B2 (B2-1, B2-2, B2-3)
K_3=2	A3 (A3-1, A3-2, A3-3)	B3 (B3-1, B3-2/, B3-3)
K_4(CK)	CK (ACK-1, ACK-2, ACK-3)	CK (BCK-1, BCK-2/, BCK-3)

Table 2. Mean tree number, basal diameter, DBH and H for Korean pine and broadleaved trees for each level of opening degree in the experiment

Plots	Korean pine			broadleaved tree		
	Number	D_0 (cm)	H (m)	Number	$D_{1.3}$(cm)	H(m)
A1	55	4.03	2.15	62	10.06	8.45
A2	35	3.48	1.73	54	11.86	10.07
A3	28	3.96	1.99	54	9.62	6.90
CK	33	3.39	1.69	51	12.44	9.92
Plots	Korean pine			broadleaved tree		
	Number	$D_{1.3}$(cm)	H(m)	Number	$D_{1.3}$(cm)	H(m)
B1	62	8.32	6.42	45	9.64	8.64
B2	42	6.72	5.39	33	11.55	8.92
B3	52	6.98	6.04	32	13.52	11.25
CK	49	6.07	5.10	67	10.81	9.17

Data collection and processing

Data of basal diameter, diameter at breast height (DBH) and height(H) of Korean pine trees, DBH and height of broadleaved trees was collected in March 2004 just after thinning and in November 2004, 2005, 2006 and September 2007. Net increment of Korean pine trees between March 2004 and September 2007 was measured for the above growth indexes.

Newly measurable and dead trees were recorded each time. The crown size, height under branches and first living branch, and diameter at half and 1/10 height were measured in September 2007.

Needle samples from Korean pine sample trees were collected. The sample tree crown was divided into upper, middle and lower layers. Current year needle samples and perennial (mainly 2 and 3 years old) needle were collected separately. Fresh needle samples were weighed right away after they were collected. Then, the needle samples were oven dried at 65°C to constant weight. The moisture content and dry weight of needles were calculated. The leaf area (A) was calculated according to Johnson (1984) and specific leaf area (SLA) were calculated according to Chmura et al. (2007).

$$A = 2L\left(1 + \pi/n\right)\sqrt{nV/\pi L}$$

where A is the leaf area; L is the cumulative needle length of the sample; n is number of needles per fascicle; V is displaced volume of the needle sample.

SLA = A of needle sample / dry weight of the needle sample.

Natural pruning capacity (NPC) = height under the first living branch / tree height

Normal form quotient (NFQ) = diameter at half height/ diameter at 1/10 height

Data were processed by Excel 2007 and SPSS 13.0.

Results and analysis

Increment of basal diameter, diameter at the breast height, and height

In Stand A (planted in 1989), the net increment of mean basal diameter and height of Korean pine trees from March 2004 to September 2007 was 1.38 cm and 0.59 m, 1.22 cm and 0.55 m, and 1.26 cm and 0.62 m for A1 regulation level with K=1, A2 regulation level with K=1.5, and A3 regulation level with K=2, respectively (Fig. 1). In Stand B (planted in 1982), the values were changed to 1.41 cm and 0.73 m, 1.32 cm and 0.73 m, and 1.14 cm and 0.78 m for B1 regulation level with K=1, B2 regulation level with K=1.5 and B3 regulation level with K=2, respectively, only the basal diameter was changed to DBH (Fig. 2). The mean basal diameter and height of Korean pine trees was only 0.86 cm and 0.36 m, respectively, in control plots, and the basal diameter and height increment of A1, A2 and A3 regulation level was 60.5% and 63.9%, 41.2% and 52.8%, and 41.7% and 72.2% higher than that of control, respectively. The number was substituted by 0.77 cm and 0.43 m, 83.1% and 69.8%, 71.4% and 69.8%, and 48.1% and 81.4% for Stand B. There was no significant difference for the net increment of basal diameter in Stand A or DBH in Stand B and height between the three regulation levels but significant difference between control and the three regulation levels ($p<0.05$).

Natural pruning capacity

In the two stands, there was no significant difference between height under branch, height under first living branch of three regulation levels and control (Table 3). Although only the Natural pruning capacity (NPC) of B3 regulation level was significant difference from that of control BCK, the NPCs of controls were 45.5% and 12.0%, 14.3% and 21.7%, and 33.3% and 33.3% higher than K=1, K=1.5 and K=2 levels in Stand A and Stand B,

respectively (Table 3). This implies the regulation decreased the degree of natural pruning and enlarged the growth space of the under-canopy planted Korean pine trees.

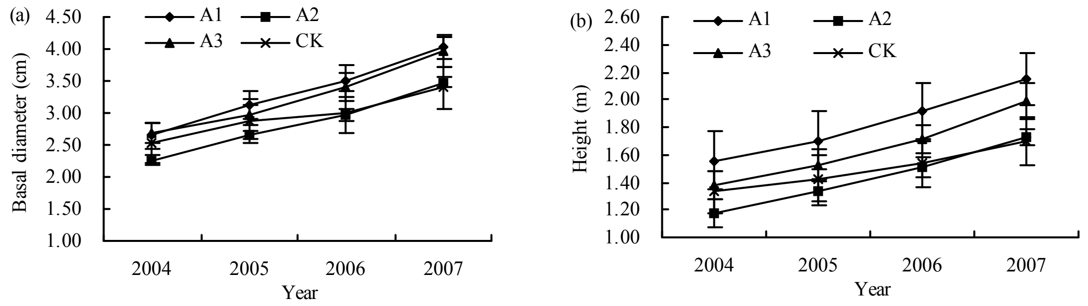

Fig. 1 Growth of basal diameter(a) and height (b) from March 2004 to September 2007 with Korean pine trees planted under canopy in 1989

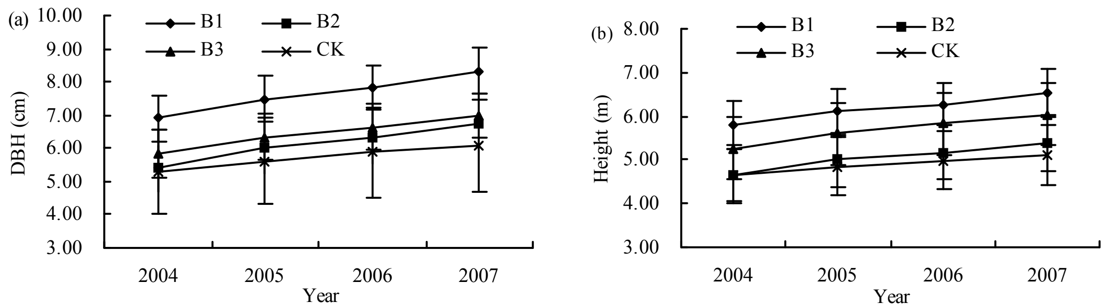

Fig. 2 Growth of DBH (a) and height (b) from March 2004 to September 2007 with Korean pine trees planted under canopy in 1982

Table 3. Height under branch and natural pruning capacity of Korean pine trees planted under secondary forest in different regulation level in the two experiment stands

Stand A	Height under branch (m)	Height under first living branch (m)	Natural pruning capacity
A1	0.18a	0.22a	0.11a
A2	0.20a	0.23a	0.14a
A3	0.19a	0.24a	0.12a
CK	0.22a	0.27a	0.16a
Stand B	**Height under branch (m)**	**Height under first living branch (m)**	**Natural pruning capacity**
B1	0.24a	1.62a	0.25ab
B2	0.27a	1.22a	0.23ab
B3	0.24a	1.22a	0.21b
CK	0.23a	1.49a	0.28a

Normal form quotient

Same patterns for normal form quotient (NFQ) with height under branch and NPC of Korean pine trees planted under secondary forest in different regulation levels were shown in Fig. 3. In the two stands, there were no significant differences between normal form quotient of the regulation levels and controls. However, the increased ratio of the NFQ of regulation levels to controls (A1/ACK=-1.21%, A2/ACK=-2.27%, A3/ACK=-5.14%; B1/BCK=7.41%, B2/BCK=5.25%, B3/BCK=3.40%) shown that the stem taper degree was decreased along with the increase of opening degree (Fig. 3).

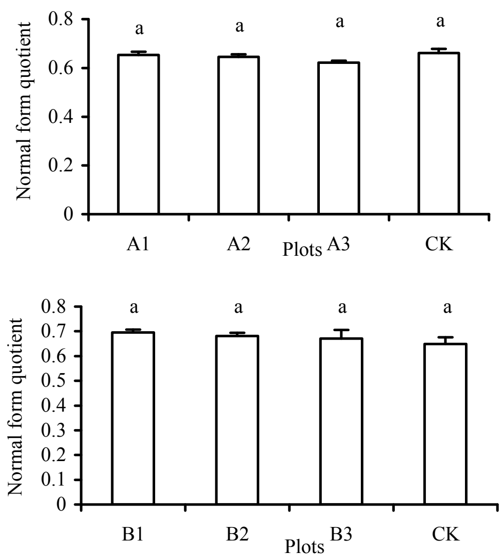

Fig. 3 Normal form quotient of Korean pine trees planted under secondary forest in different regulation levels

Crown size

Data of crown size of Korean pine trees planted under secondary forest in different regulation levels in the two experiment stands

were shown in Table 4. In the two stands, there were no significant differences between the crown size of regulation levels and that of control. The crown developed uniformly to each direction, which implied that the regulation of the individual living environment was appropriate and homogeneous.

Table 4. Crown size of Korean pine trees planted under secondary forest in different regulation levels

Stand A	Crown size (m)			
	East	South	West	North
A1	0.71±0.04	0.68±0.05	0.67±0.05	0.70±0.04
A2	0.57±0.03	0.57±0.03	0.55±0.04	0.59±0.03
A3	0.68±0.04	0.62±a0.03	0.64±0.06	0.65±0.06
CK	0.58±0.08	0.54± 0.05	0.56±0.08	0.58±0.09
Stand B	Crown size (m)			
	East	South	West	North
B1	1.39±0.01	1.33±0.06	1.30±0.04	1.30±0.01
B2	1.27±0.10	1.20±0.06	1.21±0.08	1.21±0.08
B3	1.35±0.10	1.34±0.07	1.33±0.08	1.33±0.08
CK	1.17±0.06	1.16±0.10	1.18±0.07	1.11±0.05

Specific leaf area

The specific leaf area (SLA) of Korean pine trees in all of regulation levels was higher than that of control and the increase values of SLA in Stand A were higher than that of in Stand B (Fig. 4 and Fig. 5). The SLA of perennial needles of A1, A2 and A3 regulation level in Stand A was 4.492 $m^2·kg^{-1}$, 3.263 $m^2·kg^{-1}$ and 2.973 $m^2·kg^{-1}$ higher than that of control with significant difference at 0.05 level (Fig 4), but there was no significant difference between SLAs of the regulation levels. There was no significant difference between SLAs of current needle of regulation levels and control in Stand A (Fig 4) and the same pattern was shown between SLAs of current and perennial needles in Stand B (Fig. 5).

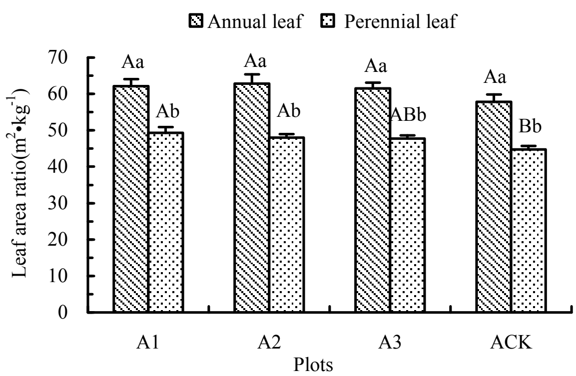

Fig. 4 Specific leaf area of Korean pine trees planted under canopy in Stand A (planted in 1989)

The capital letters indicated significant difference between SLA of each regulation levels in the same needle age at 0.05 level; the small letters indicated significant difference between SLA of different needle ages in the same regulation level at 0.05 level.

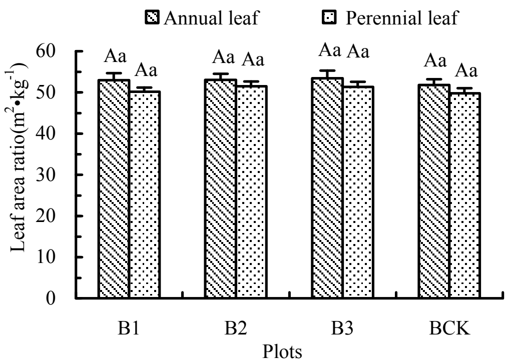

Fig. 5 Specific leaf area of Korean pine trees planted under canopy in Stand B (planted in 1982)

The capital letters indicated significant difference between SLA of each regulation levels in the same needle age at 0.05 level; the small letters indicated significant difference between SLA of different needle ages in the same regulation level at 0.05 level.

Discussion

Temperate zonal climax of Korean pine and broadleaved forest is ecologically stable and economically productive community. Recovering climax-like mixed forest from various types of secondary forests derived from the climax forest is an unremitting effort made by ecologists and silviculturists in China's northeast region. "Planting conifers and reserving broadleaved" has been improved to be an effective approach for this purpose in case there was insufficient or lack of seed sources of conifers (Chen et al. 1984, 1985). Planting Korean pine trees under the canopy of secondary forest was developed under the thought of the "Planting conifers and reserving broadleaved" strategy based on the regeneration characteristics in natural forest and proved to be an effective method that applied widely in practice (Li and Wang 1991; Li et al. 1992; Li et al. 1993; Zhang et al. 2004; Sun et al. 2004).

Since the beginning of the planting Korean pine under canopy, the growth of the under-canopy planted Korean pine trees and community status of the forest with the pine trees was paid close attention by the related researchers. Many research results indicated that the light environment was very important factor influencing the growth of the Korean pine trees planted under canopy (Pulinets 1986; Li et al. 1992; Li et al. 1993; Zhang et al. 2004; Fan et al. 2004; Shen et al. 2004). The stand structure should be regulated properly for promoting the growth of the pine trees and forming a homogeneous stand structure beneficial to the pine trees and upper-layer broadleaved trees as well (Chen et al 1984, 1985; Li and Wang 1991; Li et al. 1992; Zhang et al. 2003; Sun et al. 2004; Kong et al. 2005; Tian et al. 2005; Cai et al. 2009).

Research has proved that the Opening degree has a close co-relationship with the light environment of the under canopy planted Korean pine trees (Li and Wang 1991; Li et al. 1992; Zhang et al. 2004; Fan et al. 2004; Shen et al. 2004) and other species like *Picea schrenkiana* var. *tianschanica* (K=0.68 favor-

able to natural regeneration) (Liu et al. 2004) and *Quercus liaoturgensis* (K was the key factor influencing its regeneration) (kang et al. 2007). Therefore, Opening degree could be used as a control index for regulating the microenvironment of Korean pine trees planted under canopy of secondary forest (Li et al. 1992; Fan et al 2004; Shen et al. 2004; Zhang et al. 2004). The results described here further proved the conclusion. In the two stands, the increment of diameter and height of Korean pine trees in the regulated plots evidently higher than that of in control plots, the growth space of pine trees implied by natural pruning capacity, crown size and special leaf area were enlarged.

From the growth and space regulation effect of the under-canopy planted Korean pine trees during 4 years period for the stand of 15 to 26 years old, it could be deduced that the regulation scheme of opening degree K=1 was proper for adjusting the microenvironment of Korean pine trees planted under the canopy of secondary forest. This was similar to the result obtained by Guo et al. (1991) that K=0.9-1.1 was proper for mixed forest of Korean and *Fraxinus mandshurica*, but lower than the result obtained by Li et al. (1992) that K=1.5-1.8 and K=1.6-1.9 was most favorable to the growth of Korean pine trees planted under canopy of *Quercus mongolica* forest and *Populus-Betula* forest respectively. This difference might be influenced by other structure indexes, for our results was obtained on the background of Size differentiation, Species mingling and Contagion in a fixed value of U=0 or U=0.25, M=0.5 and W=0.5 for each plot. Therefore, more precised regulation indexes should be tested systematically.

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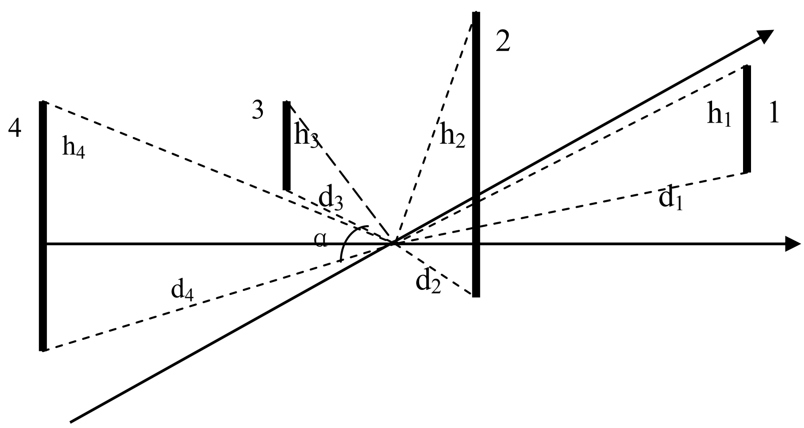
Appendix 1

The formula and schematic diagram of Opening degree (K):

$$K = \sum_{i=1}^{4} (ctg\ \alpha_i) = \sum_{i=1}^{4} (d / h)_i$$ (Luo et al. 1984; Zhang et al. 2004)

Where *i* is the neighbor number; *d* and *h* is the distance and height of one of the four trees nearest to a reference tree respectively. is the height of one of the nearest four trees to the reference tree.



Schematic diagram of Opening degree (Luo et al. 1984; Zhang et al 2004)